ADDRESS

ON

THE METRIC SYSTEM OF WEIGHTS AND MEASURES.

BY

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ON THE METRIC SYSTEM OF WEIGHTS AND MEASURES.

Mr. President and Gentlemen: When you invited me to dine with you to-day, and to address you upon some scientific topic, it was impossible not to accept the flattering invitation, for I knew that it would enable me to meet again the gentlemen to whose great kindness I was indebted for that wonderful excursion of last June, the most charming, instructive, and delightful that could be imagined, and the memory of which will always be treasured. It is needless to say that I would not willingly lose any opportunity of expressing my gratitude.

Unfortunately, my health, sadly shattered a couple of years ago, is not even yet so fully restored that it has been in my power to prepare my remarks with the care which ought to be devoted to an address in this presence. And not being able even to arrange their presentation in such form as I desired, I should have come with great hesitance had I not had good reason to know that I should be among friends who would be lenient to my shortcomings and gentle in their criticism.

Having neither the gifts nor the training for a public speaker, it has been easier to write down what I have to say than to trust to the promptings of the moment. Therefore I have ventured to bring it in written form; and you will forgive it if my words lack that sparkling effervescence from the lips which you require of your genial beverage, but come to you laden with such flatness as belongs to ideas and expressions a day or two old. In return you shall have no statement which has not been weighed and tested at leisure.

In selecting the subject it has seemed best for me to take one somewhat outside the field to which my studies have been chiefly devoted, yet regarding which I have some right to speak, while it may probably have quite as much interest for you as would one less nearly connected with your daily pursuits and belonging to regions outside of our daily affairs. And so I propose to say something concerning the metric system of weights and measures and the steps taken toward perfecting it. Not to enter upon any advocacy of its adoption for exclusive use in this country, for that would be the renewal of a crusade which it is impossible that other and abler voices than mine should not undertake at no distant day, inasmuch as its extension and furtherance are closely connected with the progress of science and the arts, of the brotherhood of nations, and, in fact, of civilization itself, but to give some account of the introduction of the system, its development, and what is going on at present toward its improvement.

In the year 1850 was published a remarkable and useful book by Mr. John H. Alexander, of Baltimore, entitled "A Universal Dictionary of Weights and Measures," and giving the values of standard weights and measures reduced to those of the United States. It contains 5,227 weights and measures, with their equivalents. Leaving aside all which are professedly distinct units, I had the curiosity to count the number of different kinds of pounds, feet, inches, pints, etc. Taking, for example, the various sorts of inches, and using not only the English word "inch," but the corresponding words in other languages, *pouce*, *Zoll*, etc., I found 60. For foot, Fuss, pied, etc., there are 135. There are 53 different distances called miles, and 29 sorts of pints, while for pound, Pfund, livre, etc., there are no less than 235!

The utter confusion created by this uncertainty need not be described. Probably most of you, gentlemen, may have had some experience of it, although the introduction of the metric system throughout the European continent has already brought relief. But, until the recent unifications of Italy, of Germany, and of the Austrian Empire, almost every petty state had its own measures, and these were changed by law from time to time. Even now, those of us who wish to know the value of various units in England find plenty of trouble. If we are told that something weighs so many stone, or measures so many quarters, it requires a considerable amount of knowledge or experience to obtain the corresponding idea.

The weight of a human being is generally given in stones of 14 pounds each; but for glass a stone is 5 pounds, for meat it is 8 pounds. In Scotland it varies, in different places, from 17 to 22, etc. Then, as to the sort of pounds, we must ask whether they are Troy pounds, and, if so, whether Scotch or English, or Tron, or the now customary avoirdupois pounds. A "quarter" may be the imperial quarter of about 8¼ bushels or the Winchester quarter of just 8 bushels; yet, when we come to bushels, there are some 40 different sorts—according as we may be measuring apples, or barley, or beans, or bran, or coal, or corn, or salt, etc.

There was, and is, but one remedy for this condition of things; and yet it was not until the beginning of the French Revolution, a century ago, that any practical steps were seriously undertaken to bring about a cure.

It was then proposed to enlist all civilized nations in a joint effort to create and adopt a new system, founded on some one unchanging natural unit as the standard of length. From the unit of linear measure, once established, it would be easy to derive those of surface measure and of volume. The measure of volume or bulk would, of course, supply that of capacity for solids or liquids, and that of weight or mass would then be afforded by that of a quantity of pure water, taken at the temperature of greatest density and corresponding to the unit of volume. It was further resolved that all the multiples and subdivisions of these units of length, area, volume, weight, should be decimal only, and that only these should be employed for all measurements of every sort and nature. The Arabic numerals, with their decimal notation, are among the very few things which are the same for all civilized mankind; and the decimal system which these imply was to be carefully maintained for every dimension which they are employed to express. It is probable, too, that the American decimal currency, just then established, was an important agent in impressing our French allies with the extreme convenience of carrying through the affairs of daily life the same numerical system which is employed in expressing all abstract values. And yet another condition laid down was that each unit should receive a name of its own, incapable of being confused with any other.

The ablest scientific men of France—men whose names are held to-day in as high reverence as during their lives, if not higher—warmly espoused this plan; and it was fully indorsed by the Paris Academy of Sciences. To secure the cooperation and assistance of other nations the National Assembly provided that all should be invited to join in the plan, and especially that the concurrence of Great Britain should be solicited. For some reason—probably the intense and reciprocal hostility of the two peoples, reenforced doubtless by that dislike of all change which is so characteristic of the English—this last provision was never carried into effect; yet, in the original consideration of the project, representatives from Spain, Italy, Netherlands, Denmark, and Switzerland took part. A committee had been appointed by the French Academy to decide upon the most appropriate natural standard. Various suggestions were considered, and it was finally decided to employ some one derived from the dimensions of our earth itself. And after long and mature deliberation the choice between the several standards was narrowed down to three—the length of the pendulum beating seconds in the forty-fifth degree of latitude, the length of the earth's circumference at the equator, and the distance from the equator to the pole. Ultimately the last was selected; and it was resolved that the ten-millionth part of the quadrant of a meridian should form the basis of the new system and should be called a meter. This would be of convenient size, intermediate between the many values of the ell, less than one-tenth longer than the yard, and, in fact, not very diverse from the accustomed units of linear measure in most civilized countries. Their report was made to the academy in March, 1791, approved and transmitted at once to the National Assembly, by which it was sanctioned and the needful provisions made for carrying it into effect.

The new universal unit was to be deduced by an elaborate determination of the length of the quadrant from equator to pole; and this was to be obtained by a geodetic triangulation, made with all possible precision, and over as long an arc of the meridian as possible. The work began at once, and the great undertaking of a measure of the meridian through the ten degrees from Dunkirk, at the northern extremity of France, to Barcelona, in Spain—a meridian which passes through Paris—was carried on for seven years under the direction of able and enthusiastic mathematicians and astronomers. In early life it was my privilege to occupy somewhat intimate relations with two of these men, Biot and Arago, then, of course, in advanced years; and it thrills me yet to remember their accounts of the privations and perils which they encountered in prosecuting the work during the terrible convulsions which distracted France through that period—making their observations in remote or dangerous regions, where the absence or presence of population were almost equally to be feared, and actually suffering capture and imprisonment.

In the year 1799 the observations had been completed and the principal results computed; and an international commission, containing representatives of 10 independent States, was then convened at Paris to deduce and establish the precise length of the proposed meter. One midsummer day of that year the standard bar which represented the unit of length, and the standard kilogram for the unit of weight—both made of platinum—were formally deposited for safe-keeping in the Palais des Archives at Paris. Copies of the same, prepared with exceeding care, were also deposited at the Conservatory of Arts and

Trades, and at the observatory. These have been since then the standards for the world, and with them have been minutely compared the standards constructed for the use of other countries.

In selecting names for the various weights and measures resulting from the meter and its corresponding units, it was rightly deemed a matter of high importance that new words should be employed. And in deciding upon these, I can not think that the commission was fortunate. For although the nomenclature is very ingenious and elegant, it has an element about it which may easily pass for pedantry, and is ill adapted for employment in most modern languages. Indeed, this seems to have been at first the very greatest obstacle in the way of its adoption, even in France itself. The decimal multiples of the primary units are denoted by prefixes taken from the Greek; and the corresponding subdivisions, by prefixes derived from the Latin. Thus, 100 meters are called a hectometer, while the hundredth part of a meter is a centimeter; a thousand grams make a kilogram, and the thousandth part of a gram is a milligram. For some European nations these words have been easily modified so as to conform to the spirit of their language; in others, and especially in English, this is not easy.

The metric system is now the only legal system of weights and measures for about 410,000,000 of people—the only prominent exceptions to its general use being in Russia, the United States, and Great Britain, in the last two of which, indeed, its use is authorized, although not generally adopted.

I have described the origin of the system with some detail, both because it seems to me an important event in the history of civilization, and because sundry criticisms, emanating from some of our ultra-conservative kindred on the other side of the water, have tended to create erroneous impressions. It has been spoken of as a French, and not a cosmopolitan institution: whereas in truth no efforts were spared by its authors to give it a thoroughly international character, so far as possible. Various nations were associated with its origin, a still larger number with its definite establishment, and now its adoption by a vast preponderance of the civilized nations has removed every possible tinge of localism and made it absolutely cosmopolitan, with the one possible but not necessary exception of its nomenclature. Then, it has been said that the value obtained was not correct: that the adopted value is now known not to be exactly the ten-millionth part of a quadrant. To this it may be replied that the objection is frivolous: that it matters not in the slighest whether the adopted value were absolutely correct or not; that the adopted standard is a certain bar of metal at a certain temperature, aiming to represent an ideal value, and that any small deviation from such value is of absolutely no consequence. But let me tell you just how much foundation that criticism has, whether important or not.

It will not and never could be supposed that the progress of science and the arts in a century would not permit the methods of observation or the instruments employed to be so improved that a repetition of the original investigation would not give slightly different and doubtless more accurate results. Unimportant but real differences would unquestionably be found whenever the measures should be repeated. This has, however, not been done, nor is there any reason to suspect inaccuracy in the former determination, other than the imperfection which belongs to all work of men's hands. For that epoch the results seem to have been marvelously accurate. But since then similar triangulations and measurements have been made in many countries—Russia, India, South Africa, the United States, Chile, and elsewhere—and they have brought to light the unexpected fact that the earth is probably not a regular spheroid; for the distance by which its polar axis is shorter than the equatorial is given differently by each successive measurement in a new region, and indeed by different parts of the same measurement, the results varying by comparatively large amounts; and the inference is nearly irresistible that our earth is not accurately a spheroid of rotation, but that its equatorial diameter varies in different longitudes. Thus, the length of a quadrant in one meridian is different from that in another meridian. Possibly the meter may differ from its intended value—the ten-millionth part of the quadrant which passes through Paris—by about the two-hundredth part of an inch; and yet the same results concerning the true figure of the earth, which give that inference, make the meter to be almost precisely the ten-millionth part of a quadrant of the meridian passing through New York—differing in fact from this by less than the ten-thousandth part of an inch. This would make the actual quadrant for New York to differ from 10,000,000 meters by about 80 feet. So that were the objection of any importance, it could be readily disposed of by a slight change of definition, putting the word New York instead of Paris. It might be, also, by a modification of the temperature at which the length of the bar is to hold good.

But all these considerations are practically unessential. The practical end in view was to secure some definite and material standard of length, upon which all nations should agree. It was evidently desirable that this should be derived from some natural dimension; and since, owing to the want of absolute precision in any work of human hands, it can not be expected that any degree of accuracy should be attained which may not subsequently be surpassed, it suffices amply that a near approximation be reached. Each successive future determination will give a slightly different value; and this state of things will continue so long as the earth itself lasts, and would be just as true of any other natural standard as of this.

The new system was forced upon the French people by compulsory legislation, and without giving them proper instruction as to its nature and peculiar features. Naturally it aroused opposition, for the new units required a violation of their confirmed habits and prejudices; yet a very few years sufficed to make them not merely familiar with but cordially attached to it. The same is true, in a yet higher degree, of those countries into which it was soon carried by the conquests of the Empire; for it was a constant reminder of their subjugation, and it was repudiated by most of them on their emancipation from the French yoke. Yet, notwithstanding these obstacles to its resumption, its excellencies are such as to have brought about since then its voluntary adoption by them all.

The consolidation of different states requires a unification of their weights and measures; and, in agreeing upon a new system, they naturally desired to select the best. And, furthermore, one which should be in common with other nations would, even if a poor one, be evidently preferable to any other which had only a local application. Statesmen needed it for their custom-houses, and it has already done much toward abolishing frontiers; scientific investigators, who form but a very small class in any one county, needed it for their common researches and the comparison of their results; artists needed it for analogous reasons; so, too, did medical men, whose experience ought to be shared by their colleagues of all nations; artisans and mechanics, those whose products were to be exported to other lands, as well as those who imported from outside their own boundaries; commercial men, who might thus avoid troublesome conversion of their invoice values; engineers in different lands, who could escape petty and vexatious changes of dimensions to make their results mutually comparable, and so on.

To-day the only states of continental Europe in which the metric system is not fully established as the only legal one are Russia, Sweden, Denmark, and Turkey. Even in these it is permissive in all but Denmark and Russia; in Sweden it goes into operation next January, while the Danish system is based upon metric values, so as to be easily convertible into them. On our own continent, it has been adopted as the one legal system by Mexico, Brazil, and almost all of the South American Republics. In short there is a total of more than 400,000,000 people thoroughly committed to the metric system, besides the hundred and twenty-two millions for whom it is permissive. There remain no civilized nations of any importance, excepting Russia and Japan. When the system shall have been fully adopted in our own country, as I firmly believe it will before many years, none except these two and England will remain outside, if indeed they do. For all three of them are already members of the international metric league, of which I am to tell you, and all contribute annually to its support.

It scarcely needs especial mention to remind you that the importance of the highest accuracy and extreme care in the preservation and verification of the standards of measure and of weight is quite as decided from a scientific as from a commercial point of view. In the delicate researches of physics and chemical science, which deal with quantities far below the reach of our microscopes, this precision is no less but indeed far more requisite than in the explorations of the astronomer. The relative atomic weights, the structure of crystals, the dimensions of the various waves of light, the expansion of bodies by heat, the units of force, and numberless other subjects of research demand not only the highest precision attainable, but likewise a uniformity of the standards employed by different investigators. Not only is the number of explorers of nature's laws very small, but they are distributed through many countries and working under varied conditions. If their researches are to result in the greatest common progress, their standards of dimension must be identical, or very easily converted. Geodetic investigations, too, must be comparable with one another, as well as those in physics and in chemistry.

For this reason it has long been the custom for physicists and chemists of all lands to conduct their researches in metric units. And there would be little danger of error in saying that more than nine-tenths of the chemists of the world and three-fourths of all the physicists—English, American, and Russian, as well as others—employ exclusively the meter and the gram. Yet what security has there been that the standards for even these units, existing in different countries, were practically identical?

The need of securing actual, as well as nominal, uniformity in the units employed had been making itself felt more and more through a series of years, until in 1868, the Government of France, at the instance of the European Geodetic Association, issued a circular to all the nations with which it was in diplomatic relations, inviting them to appoint delegates to a conference at Paris in 1870, in order to adopt measures for securing permanence and uniformity in the various standards of weights and measures, and to devise means of reproducing these standards with all possible accuracy.

Agreeable to this invitation the delegates of 24 nations, representing the majority of civilized human beings, assembled in Paris on the 8th of August, 1870. The time proved most unfortunate. War had been declared less than three weeks before, the representatives of Prussia and England were absent, and the condition of affairs was as unfavorable as could well be for scientific thought or deliberation.

Still some action was had in agreeing upon certain general principles which might be followed. And it was resolved that measures should be taken for extending the international character of the metric system, but without undertaking any modification of the existing value of the meter. Various ends to be attained were clearly defined. A commission representing 30 nations and containing some of the most eminent scientists of Europe was appointed to make the preliminary experiments and investigations, and definite principles were laid down to guide them. Among the duties with which they were charged was that of making a careful study of the properties of such materials as might appear to be suitable for the construction of the new standards, and into the best forms and modes of construction. The French Government promised its full support to all the decisions of the conference, which then adjourned until some more auspicious time.

During the session of this conference its members had made a formal visit to the bureau of archives in order to inspect the platinum standards there deposited. These had been found in excellent condition; and among the rules recommended was one to the effect that as many copies of them should be made as there were nations represented, and with all the precision which the resources of science and the arts would permit; that one of these be selected as an international prototype for all future time and preserved with every precaution, while the others should be distributed among the participating countries; also that an analogous course should be pursued with reference to the standard kilogram.

The need of such precautions as these had been signally illustrated during the year following this conference. At the same time that the Tuileries were burned by the commune orders had been given to destroy the archives of France simultaneously with the other public buildings and the column of the Place Vendôme. It was only through an accident that the plan failed; but in the meanwhile two of the members of the commission had secretly abstracted the standard meter and kilogram from their place of sacred deposit, and had hidden them elsewhere, inclosing a statement of the hiding-place in a sealed letter, deposited with the Academy of Sciences.

The international commission distributed the subjects referred to it among ten subcommittees; and two years later, in the autumn of 1872, it reassembled at Paris for definite action. A full plan of operations and a most elaborate code of recommendations for their execution were then agreed upon, as well as a resolution asking the French Government to invite another international conference for the purpose of acting on these recommendations and of considering the establishment of an international bureau to take charge not merely of the construction of the new prototypes, but also of the preservation of the international standards, and their periodical comparison with those prototypes, which were to be distributed among the several nations, and with such other fundamental standards as have been or are to be used for geodetic or other important operations.

On the 1st of March, 1875, the new conference was held, consisting of the representatives of twenty-one nations; England only having declined out of all those invited.

The commission presented its results, and an international league was formed by an agreement in the nature of a treaty under the name of the "metric convention." By this compact, which has now been in practical operation for nearly twelve years, the several constituent nations agreed to maintain, at their joint expense, an international bureau of weights and measures at Paris. This was to be conducted under the exclusive direction and control of a so-called "international committee," subject in its turn to the authority of a "general conference of weights and measures," a body of diplomatic character and composed of delegates appointed by and representing all the contracting powers.

It was provided that the international committee should be composed of fourteen members, each belonging to a different nationality and charged with the duties of superintending the new prototypes, of verifying them when completed, of preserving the international ones, of superintending such other operations of the sort as might be undertaken by the nations in common, of making periodical comparisons of the standards distributed to the different nations, of verifying and comparing the measures which have been or might be employed in geodetic operations, etc. (not only for governments but for scientific institutions), of providing the requisite apparatus, etc.

The bureau of the establishment was to be established at Paris, in some building to be specially prepared or constructed by the committee, and the French Government to give it legal immunities.

The contributions of each nation were to depend upon its population and upon the employment which it makes of the metric system, whether it is obligatory, or permissive, or neither.

And, finally, it was provided that the deliberations and votes of the committee might take place by correspondence, excepting that one session be held annually, up to the time of the completion of the prototypes, and one in each two years thereafter; the conference itself (the diplomatic body) to be convened when the prototypes were ready and afterwards at the call of the committee, as often, at least, as once in every six years.

Such is the metric convention, now composed of all the principal nations of the civilized world excepting Holland and Brazil, in both of which countries, however, the metric system exclusively prevails for legal use, but which other considerations have hitherto prevented from definitely joining the league. In the unanimous report of a committee of the American Association for the Advancement of Science, among whose eight members were President Barnard of New York, Professors Henry of Washington, Rogers of Boston, and Peirce of Cambridge, this international league was declared to be "more honorable to civilization than almost any other that was ever entered into by such high contracting parties."

The international committee entered at once upon its duties, beginning in April, 1875. After careful examination and deliberation they selected an edifice of some historic interest, known as the Pavillon de Breteuil, situated near the entrance of the Parc de St. Cloud, not more than a gunshot from the celebrated porcelain factory of Sèvres, which it overlooks. The French Government has given the use of the land and building, and declared it international territory so long as it shall be devoted to its present purpose. Here have been built the workshops, laboratories, and the subterranean vaults for depositing the standards; and here go on the experiments and researches of every kind.

The platinum *Mètre des Archives* was established as the standard to which the new ones must be made to conform with all possible accuracy. This has been found to differ slightly from the platinum *Mètre du Conservatoire*, not only in its coefficient of expansion—that is to say, the amount of its increase of length for the same increase of temperature—but also in its actual length at the standard temperature, at which the difference amounts to nearly four-thousandths of a millimeter—that is, to about the sixty-two hundredth part of an inch. The different value of the constants of expansion for the two bars can only be accounted for by some difference of chemical constitution or of density, notwithstanding that they were constructed by the same maker and at the same time. Probably they were cast at different meltings.

In preparing the new standards it was the firm resolve of the international committee that no source of error or uncertainty should be left which human knowledge or skill could avoid. To escape all danger of any modification by atmospheric influences by molecular change or by use, it was requisite that the material should be the most refractory and hardest attainable, absolutely homogeneous, and of the highest purity. After many experiments and much study it had been decided by the commission of 1872 that an alloy of platinum and iridium should be employed, combined in the proportions of 9 to 1, with a tolerance of not more than 2 per cent in the proportion of either, and that especial care should be taken to avoid the smallest intermixture of any one of the three metals which would most endanger its permanency, whether as regards extremes of temperature, or atmospheric influences, or molecular changes. These three metals, which are almost always found combined in small quantities with platinum and iridium, and are peculiarly difficult to remove by chemical processes, are iron, ruthenium, and osmium; the alloy of the last with iridium being what we all know in the nibs of our gold pens.

The preliminary preparations having been concluded, and the constituent metals obtained and purified, the melting was first essayed on a small scale; and these results appearing satisfactory, the casting of a large mass took place with great state. The work had been intrusted to the French members of the original commission—members of the Academy of Sciences, and of a world-wide reputation. A large crucible of chalkstone had been made and special furnaces, heated by huge oxyhydrogen flames, constructed. The President of the Republic and the minister of public instruction were present and a number of the members of the Academy of Sciences. The heat produced was so intense that in a few minutes the metals—among the most difficult to melt of any known—were converted into a glowing mass as brilliant as the sun. This was poured into the chalk mold to form the ingot, which was not far from 44 inches long, 7 wide, and 3 thick, if I may venture to name its dimensions in such vulgar units. It weighed about 200 kilograms, or, say, 440 pounds. When it was exhibited to the Academy of Sciences four men were needed to carry the tray on which it rested; yet had it been an ingot of aluminum of the same size it would have been easy for any of us to hold it out at arm's length.

From this a kilogram weight was prepared and furnished to the international committee for its preliminary study; but, to the dismay of all, the impurities, especially the metal ruthenium, were found by them to surpass the limit of tolerance prescribed, being about 2¼ per cent instead of 2 per cent. The whole mass of material had to be rejected, a proceeding not at all acceptable to the gentlemen under whose direction it had been prepared. They declared it impossible to obtain greater purity, professed to regard the committee's action as an indignity to their nation, and the discord threatened at one time seriously to imperil the existence of the international committee. But one of its members, M. Stas, of Brussels, with the aid of that gifted French chemist, the late H. St. Clair Deville, took up the problem; and within less than two years they had devised and carried out a new process, by the aid of which it has been possible to obtain material almost pure, the amount of impurities of every kind in the material finally employed being less than one-fourth of 1 per cent, or amounting to only about one-tenth of the tolerance which had been originally fixed as the limit. It took seven years to attain this end, but it has been attained.

Then came the question of form. For the kilogram standards this was easy to decide. The weights are nearly cylindrical, having a diameter equal to the height, while the edges above and below are rounded to avoid angles. But for the meter bars this question was serious. The temperature at which the measurements are made is a very important element; and although the surface temperature of the bars may be easy to determine, it is very difficult, if not impossible, to know how far that temperature is uniform throughout the mass. To be sure, the standards are kept for some hours previous to use in the same circumstances of position and temperature in which the comparisons are to be made—generally in a bath of glycerin, maintained at a fixed and uniform temperature by especial precautions. Still, there is always a possibility that there may be some difference of temperature between the interior and the surface; and so the form given to the meter bars is such that their cross section is nearly in the shape of an X, the narrow plane on which the divisions are traced being at the upper angle and just in the middle line of the bars.

The question of support has been a serious one, lest there be any tendency to bend; but more troublesome still has been that of the polish of the surface on which the divisions are traced. These divisions are read by microscopes; and the mode of illumination is necessarily different for a dead polish and for a bright specular one. Of course, the mode of tracing the divisions, their depth and shape, have received careful study; and there seems to be left no opportunity for reasonable doubt as to the completeness of every precaution. The international standard is to be deposited in the subterranean vault, upon a carriage specially devised, and accompanied by three others, each of which has been minutely compared with it; and the whole, together with the kilogram standards, closed with three locks, one key being in the custody of the president of the international committee, one in that of the director of the bureau, and one in that of the director of the French bureau of archives. Thus there will be no possible access to it, except by the concurrence of these three officials, and not even for the director of the bureau, except by a vote of the international committee and in presence of two of its members.

The kilogram standards are now completed. The old standards of the Archives and the Observatory were also found to differ from one another by an amount perceptible with the new balances. The former was adopted as the standard; but, although its weight will be extremely close to that of a cubic centimeter of pure water at the temperature of greatest density, the case is like that of the length of the meter already spoken of; and its deviation from the absolute theoretical value will doubtless become more and more appreciable with the advance of arts and sciences. At present it is not surely known whether it is in excess or defect; but the researches now making at the bureau of the international committee will doubtless solve that question before long. The temperature of greatest density for water is first to be fixed. This is only known at present to within a fraction of a degree of the centigrade scale. A department of thermometry has been recently established at Breteuil, and investigations have been making which will greatly add to the precision with which temperatures can be determined. Various sources of error have been discovered, to which the best thermometers are subject, apart from possible want of uniformity of the caliber of different parts of the tube. It has been found that the chemical composition of the glass employed exerts a very decided effect, owing to the consequent difference in the relative expansion of the glass and the mercury.

The most delicate and accurate thermometer that has thus far been made is one which employs pure hydrogen gas instead of mercury; and this has been adopted as the standard thermometer, by whose indications all others are tested. Also the coefficients of expansion for the material of the standards, as well as for pure mercury, to say nothing of the various sorts of glass used, have been determined with a precision never before attained, whether we consider the methods employed or the minute and punctilious care with which the work is prosecuted.

In short, it has been the aim of the committee to be satisfied with no results of any sort not in advance of what the world had previously attained. Composed of representatives of fourteen different nations, it has been hoped that their joint efforts would lead to results beyond what could be expected from any one man; and it may fairly be claimed that up to the present time no one of the various arts or sciences whose aid has been required has failed to receive a decided and important impulse from the demands made upon it by the International Bureau. The new and wonderfully delicate apparatus for graduating the bars, for comparing the finished standards, for preserving uniformity of temperature, for determining the coefficients of expansion, for calibrating thermometer tubes, the balances for weighing heavy objects in vacuum and in water, the chemical processes for purifying the metals, the mode of fusing them, and the mechanical processes for fashioning them, the exquisite form and evenness of the divisions, traced upon metal of more than adamantine hardness, no less than the accuracy of the graduation itself—these represent but a part of the many advances due to the International Bureau; and it is scarcely too much to say that in every one of these directions progress has been made to an extent unknown, if indeed considered possible, a dozen years ago.

Let me give one little illustration. In 1880 a certain number of the kilograms had been completed, and it was necessary to determine the discordances of each from the old standard, preserved in the French archives, and to which the new international standard was to be made as closely approximate as possible. Four of them were thus compared, and all found very close to the original. One of them seemed a little nearer than the others, and differing, indeed, almost imperceptibly from the standard, yet certainly a little heavier. Its material was, of course, this so-called platin-iridium, so hard that a diamond point marked it with difficulty, and so heavy that when put into mercury it would fall to the bottom with a splash like that of a stone in a pail of water. Professor Stas, the eminent chemist who represents Belgium in the committee, undertook the task of bringing it still more closely into conformity, and succeeded in doing so by taking the weight into his hands, clad in white kid gloves, and rubbing it with his forefinger. Since then it has been impossible to ascertain which of the two is the heavier at the standard temperature. Raising or lowering the temperature a very little, the difference due to the slight difference in the changes of their bulk thus produced becomes perceptible, for the buoyancy of the surrounding air or water is thus made appreciable; but when weighed in a vacuum their weights are sensibly equal at all temperatures.

Weighed in air of the adopted temperature and barometric pressure, the index of the balance, which of course is inclosed in glass, will be seen to rise on that side which the observer approaches most nearly. Some curious and rather disturbing experiences have made this fact altogether too palpable.

The particular piece of metal of which I speak has now been adopted by the committee to be the international prototype of the kilogram; and when the decision of the committee shall have been approved by the diplomatic conference, which will be summoned for the purpose so soon as the national prototypes are ready for distribution, this will be the only standard for the world, superseding all others for legal purposes, even in France, where the orignal one from which this was derived will cease to have other value than the historic.

It will readily be seen that all this work has taken time. Nine years passed after the organization of the International Committee before the material for the standards was obtained with satisfactory purity and in sufficient quantity, and many of the delays have been most vexatious. But there is every reason to believe that in the course of another year all the standards of weight and measure bespoken by the several constituent nations, as well as the international prototypes of length and weight, together with the three subsidiary ones which are to authenticate each of these, will be completed. The diplomatic conference will then be convened to confirm the acts of the committee, the national prototypes will be distributed, and the second stage of the committee's labors will begin.

Had I not already occupied so much of your time, there are one or two other points which might perhaps have some interest for you. Such, for instance, is the mode of measuring with the meter bars, the ends of which were formerly used, but which can not well be employed with sufficient precision in this way, the length being now given by the distance between two lines, traced near the extremities and observed with microscopes. Such, too, is the difficulty which has been found in placing distinctive marks upon the several weights without impairing their accuracy, since any cavity made by a graving tool invites dust. And so on. But I will mention one matter more.

In the search for natural standards it was found out of the question to find one which could be easily redetermined; but that difficulty seems now to have disappeared. The discoveries of recent years have afforded means for measuring with great precision the dimensions of the waves of light of any color; and this, which was once only a theoretical, ideal unit, promises now to be the most trustworthy and easily determinable of all. The International Committee will probably at no distant time determine these dimensions in metric units for rays of several different colors, and thus provide a new definition for the adopted standard.

It may be worth mentioning to you that all the members of the International Committee serve in that capacity without remuneration, except that most of the governments refund to their representatives their necessary traveling expenses in attending the sessions.

In concluding, let me read a short passage from the report of the committee of the American Association for the Advancement of Science, to which I have already alluded. They say—

> It is to be considered that this organization is not designed merely to advance the interests of the metric system of weights and measures, or to serve as a means of promoting the extension of that system. Its design is higher than that. To secure the universal adoption of the metric system would be, undoubtedly, to confer an immense and incalculable benefit upon the human race; but it would be a benefit felt mainly in the increased facilities which it would afford to commerce, and to exactness in matters that concern the practical life of humanity. But to secure that severe accuracy in standards of measurement which transcends all the wants of ordinary business affairs, yet which in the present advanced state of science is the absolutely indispensable condition of higher progress, is an object of interest to the investigators of nature immensely superior to anything which contemplates only the increase of the wealth of nations.
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> This International Bureau proposes now to provide for science precisely that which science in the present age of the world demands—such minute exactness of measurement that observations of the most delicate character which may be made in Germany or Italy or France or England may be exactly and quantitatively known to the investigator in the United States who reads the measures as they are set down in the journals and the memoirs in which the original observations are described. It is of secondary consequence whether the standards are metric standards or standards which are in use among ourselves. This bureau will equally verify them all and compare them all with standards of other nations founded on different linear bases, so long as such differences shall continue to exist. It is therefore not merely an International Bureau of Weights and Measures, but it may with equal propriety be called an international bureau for the promotion of exactness in scientific determinations; and it will be as much the organ of institutions like this association, like the National Academy, like the Royal Society, like the French Institute, etc., as it will be that of the governments establishing it.